have all been used to determine the date when °D accumulation should begin. Early in the season, degree-days accumulate slowly, and the rate peaks in July or August.

In Fresno, using a lower threshold of 50° F as an example, each of the four years shown in table 3 was distinct, with 1981 accumulating the most °D and 1980 the fewest. A greater number of °D accumulated in each of the four years than in the 30-year average. A warmer or longer season (more °D accumulation), however, does not mean that yields will be uniformly higher. In some crops, high temperatures can aggravate irrigation management problems and increase crop stress.

Insect and plant population and development models that incorporate thresholds and rates based on degree-days can help growers and pest control advisors to pinpoint biological events. The result is better pest control and crop management decisions. Table 4 lists several insect pests for which °D-based models have been developed and are now being used in California. Some of these models are very simple and provide information on the timing of events such as overwintering emergence and subsequent population buildup. The more detailed models can be used to estimate damage to the crop in determining when pest control is necessary to avoid economic loss.

Using °D to predict insect development makes it possible to minimize conflicts between cultural and pest control operations, such as between irrigation and pesticide scheduling.

Degree-days can tell growers and pest control advisors where they stand in relation to development of a generation of insects or a disease so that they can time pesticide applications more efficiently, thus often reducing costs and damage by insects or disease organisms. For example, pheromone traps might indicate an increase in the number of adults of a pest species. The accumulated °D would indicate whether this is a real or a false peak. If it proves to be false, treatment could be delayed until the next pest generation actually begins, avoiding an unnecessary pesticide application.

Degree-days also can be useful in determining when to do extensive sampling — limiting such activities to times when the pests are present.

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Weedy species of rice show promise for disease resistance

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Breeders are using weedy species as reservoirs of genes for resistance

Weedy or related species of cultivated crops frequently serve as sources of genes for disease resistance, especially when suitable genes cannot be found in the crop. Such a situation exists for the fungal disease stem rot, caused by *Sclerotium oryzae*, in cultivated rice, *Oryza sativa*. Stem rot causes significant rice yield reductions in California each year. Although the world collection of cultivated rice varieties has been extensively sampled in a search for stem rot resistance, no varieties have been found that have better levels of resistance than Colusa, one of the prominent early varieties of California. Since Colusa itself is only moderately resistant, better levels of resistance are needed to minimize yield losses from the disease.

Control of the disease by genetic resistance is the most desirable technique, since this represents relatively little recurring cost to the grower. Other possible control measures include burning of straw residues and chemical applications, but each has limitations. Burning of straw residues, in which the stem rot fungus overwinters, limits the severity of the disease by minimizing inoculum but does not completely control the disease. Also, concern over air pollution caused by smoke from straw burning has led to restrictions on the amount of burning. The chemical triphenyltin hydroxide effectively controls stem rot but is unregistered in California and thus cannot be used commercially.

We began a program in the mid-1970s to develop better sources of stem rot resistance from the related species of

TABLE 1. Disease index (DI) scores of 24 genotypes, representing 13 weedy species of *Oryza* and 4 varieties of cultivated rice, *Oryza sativa*, screened for stem rot resistance in the greenhouse, Davis

Oryza species	Genome	DI*
O. officinalis A101399	CC	2.0
O. officinalis A101121	CC	2.4
O. punctata PI 254570	BBCC	2.4
O. eichingeri PI 233491	BBCC	2.5
O. paraguayensis PI 245708	CCDD	2.4
O. officinalis A101112	CC	2.6
O. stapfii PI 254571	A'A'	2.6
O. stapfii PI 237987	A'A'	2.7
O. rufipogon A100912	AA	3.0
O. rufipogon A100923	AA	3.1
O. latifolia PI 269727	CCDD	2.7
O. rufipogon A100945	AA	3.4
O. nivara A101524	AA	3.2
O. nivara A101512	AA	3.1
O. australiensis PI 239667	EE	3.4
O. officinalis A101116	CC	2.9
O. spontanea A100943	AA	3.2
O. rufipogon A100946	AA	3.5
O. glaberrima PI 231194-3	AA	3.7
O. glaberrima PI 231194-1	AA	3.8
O. breviligulata af. 27-3	AA	3.4
O. fatua PI 239671	AA	3.4
O. stapfii PI 236393	A'A'	3.9
O. sativa cv. Tanginbozu	AA	3.5
O. sativa cv. Colusa	AA	3.7
O. officinalis A101073	CC	3.8
O. sativa cv. M-101	AA	4.0
O. sativa cv. Earlirose	AA	4.0

* DI values are on a scale of 1 to 5, as follows: 1, no infection; 2, fungus attacks outer leaf sheaths only; 3, fungus penetrates all leaf sheaths; 4, fungus infects the culm; 5, culm severely infected (rotted). LSD 0.05 and 0.01 = 0.4 and 0.5, respectively.

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Early symptoms of stem rot on rice (left), and its inward progression through layers of leaves to culm (above and facing page).

rice. Steps in this process were to collect a broad array of the related species, screen them for stem rot resistance, and then hybridize the resistant species with a California rice variety to begin the transfer of resistance to high-yielding varieties.

Twenty species of the genus *Oryza* are known, but only two are cultivated: *Oryza sativa*, sometimes called Asian rice, is by far the most important and includes all U.S. rice. *O. glaberrima*, or African rice, is cultivated in tropical Africa but is being rapidly replaced by *O. sativa*.

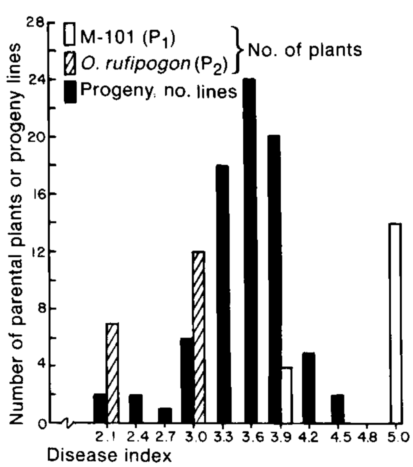
Collecting related species

Only a handful of the related species were in the United States in the mid-1970s. We requested additional *Oryza* species from the International Rice Research Institute in the Philippines, which had collected *Oryza* species worldwide. Most of the species originally came from Asia, and a few from Africa, Australia, and Central and South America. The new species were grown in a plant introduction nursery at the University of California's Imperial Valley Field Station, to avoid introduction of pests or diseases.

Only a few plants of each entry could be grown, because most of the wild species require short day length for flowering and thus must be grown in the greenhouse for light and temperature control. Other undesirable features of the related species include prostrate growth habit with stems growing in near-horizontal directions instead of vertically, severe shattering of the grain as it matures, long awns, and red seed coat. In general, the weedy species have many characters that make them totally unsuited for farm production, and even make them difficult to grow experimentally.

Screening for resistance

By 1978 enough genotypes (lines) of the related species had been assembled to begin screening for resistance. Plants were grown in the greenhouse in flooded pots, inoculated by sprinkling stem rot sclerotia into the water at mid-tillering, and scored for disease reaction 9 to 12 weeks later. Disease reaction, determined by examination of culms (stems) at maturity, was recorded on a scale of 1 to 5, where low values represent resistance and high values, susceptibility.



Several progeny (F_4 lines) retained good stem rot resistance in 1981, but in many lines, resistance did not hold.

In early 1978, 55 genotypes in 17 *Oryza* species, including cultivated rice, *O. sativa*, were screened. The most resistant 24 genotypes, representing 13 species, were screened again to recheck their resistance. Disease index (DI) scores of these 24 genotypes and 4 *O. sativa* check varieties were averaged over both screening experiments (table 1). Fifteen of these genotypes, representing 9 species, were significantly more resistant to stem rot than Colusa, the most resistant check variety.

Genome, or chromosome constitution, of each of these genotypes is also shown in table 1. Cultivated rice, *O. sativa*, which has the AA genome, can be readily hybridized with other AA genome species. Hybridization with species having genomes other than AA is extremely difficult. Unfortunately the best overall stem rot resistance was found in species with the foreign genomes. For example, excellent resistance was observed in *O. officinalis* A101399, which has the CC genome and is almost impossible to cross with cultivated rice. However, resistant genotypes of three species, *O. rufipogon*, *O. nivara*, and *O. spontanea*, which carry the same genome as cultivated rice, were identified. These results encouraged us to begin interspecific hybridization to transfer stem rot resistance.

TABLE 2. Disease index (DI) scores of parents and two generations of successful crosses with weedy *Oryza* species, all grown in the field at Davis, 1979

Cross	DI of wild parent*	DI of F_1*	DI of F_2 (± S.E.)	Number of F_2 plants
M-101 *O. rufipogon* A100912	2.1	1.9	2.7 (±0.03)	292
M-101 *O. nivara* A101512	2.7	2.5	3.1 (±0.10)	20
M-101 *O. rufipogon* A100923	3.1	3.2	3.4 (±0.03)	361
M-101 *O. nivara* A101524	3.2	3.0	3.5 (±0.05)	94
M-101 *O. rufipogon* A100945	3.5	2.7	3.3 (±0.07)	79
M-101 *O. fatua* PI 239671	3.6	2.9	3.5 (±0.08)	49
M-101 *O. spontanea* A100943	3.7	2.5	3.6 (±0.06)	75
M-101 *O. rufipogon* A100946	3.8	2.9	3.7 (±0.04)	104
DI of M-101 = 4.0				

*LSD 0.05 and LSD 0.01 = 0.4 and 0.6, respectively.

Interspecific hybridization

We started transfer of disease resistance in 1978, using the cultivated rice variety M-101 as the female parent, and the weedy species as pollen parents. M-101 was used as the cultivated parent, because it is representative of the new high-yielding, early maturing semidwarf varieties currently grown in California. We began by attempting to cross M-101 with 20 resistant genotypes, representing 12 species. Hybrid seeds were obtained in 15 combinations representing 10 species. Attempts to cross M-101 with *O. officinalis* (CC genome), the most resistant weedy species, and with *O. alta* (CCDD genome) were unsuccessful.

The first-generation (F_1) hybrid plants of crosses with 5 species were completely sterile and could not be propagated by seed. In one other interspecific combination, there were not enough seeds to continue the cross. Sufficient seeds for continuing the cross were obtained on F_1 plants of only 8 combinations, representing 4 weedy species. All of these last 4 species carry the same AA genome as cultivated rice.

Fortunately, some of the 8 donor parents were relatively resistant to stem rot (table 2). The combination with the greatest promise for transfer of resistance was M-101/*O. rufipogon* A100912, which exhibited improved resistance in both the F_1 and F_2 generations in the field in 1979. At the end of the 1979 season, we decided to concentrate our efforts on this cross and, to a lesser extent, on another *O. rufipogon* cross, M-101/*O. rufipogon* A100945. Both *O. rufipogon* parents are weedy rices from South and Southeast Asia.

Because of the weedy nature of the *O. rufipogon* donors, the F_2 populations showed a large range of segregation for maturity, plant type, awn length, and seed set. In the principal cross, we maintained a random population of all F_2 plants that matured in time to set seed in the field at Davis. Thus, the population of 292 F_2 plants was reduced to 174 at harvest.

In 1980, the 174 F_3 generation lines were evaluated for stem rot resistance in field plantings at Davis and Biggs. Stem rot resistance was found to be heritable, but the relatively low heritability levels (31 to 38 percent) indicate that considerable work is needed to recapture suitable resistance. Stem rot resistance appeared to be controlled by several genes, and reactions may be confounded by maturity and plant type of recombinants.

Only those F_3 plants with DI scores of less than 2.5 were saved from the 1980 tests. This selected population consisted of 77 F_3 plants, tracing back to 26 F_2 plants of the M-101/*O. rufipogon* A100912 cross, and 4 F_3 plants tracing back to 1 F_2 plant of the M-101/*O. rufipogon* A100945 cross.

We evaluated these 81 F_3-derived lines in the field at Davis in 1981. Several lines retained a good level of stem rot resistance in 1981, but in many lines the resistance did not hold up (see graph). However, stem rot infection was quite severe in 1981, which resulted in greater selection pressure for resistance.

At the end of the 1981 season, we chose 29 F_4 lines with low DI scores for further testing. Besides being selected for disease resistance in three consecutive generations, these 29 lines have also been selected for early maturity, erect plant type, and seed fertility. Considerable progress has been made in recombining stem rot resistance from the weedy parent with good agronomic type from the California parent, but much remains to be done to complete the goal of interspecific transfer of resistance. The principal achievements at this point have been to demonstrate the validity of using weedy species as disease-resistant donors, and to develop selected resistant lines for use in further crosses to cultivated rice varieties.

Research needs

In addition to using the selected stem rot F_4 lines in further crosses to cultivated varieties, at least three other actions are needed. First, a larger array of *Oryza* species genotypes, especially species with AA genomes, is needed in the United States. It is entirely possible that AA genome sources of stem rot resistance superior to the present *O. rufipogon* A100912 entry can be found. Second, the crosses to *O. officinalis*, the CC genome species with the best stem rot resistance observed in this study, should be attempted again. Literature reports indicate that occasional hybrids with *O. officinalis* have been made in Japan and Taiwan. The F_1 lines were sterile, but techniques such as embryo culture might be useful to overcome the sterility.

Finally, the related weedy *Oryza* species may be reservoirs of genes for resistance to other diseases and pests. For example, the weedy species are being screened for resistance to sheath blight, another fungal disease that is becoming noticeable in California. As in the case of stem rot, no sources of suitable resistance for sheath blight are available in cultivated rice. Other possibilities for use of weedy species as donor parents will no doubt become evident in the future.

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